

Low Noise Receivers: Theory of “Noise Bursts” on Large Antennas

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When a large paraboloidal antenna is used simultaneously for high-power transmission and low-level reception of signals at different frequencies, it is a frequent observation that anomalous and random noise bursts appear at the receiver output. A further observation is that, if simultaneous transmission is made at two closely separated frequencies, the intermodulation products (IMPs) of high order number will often appear at the receiver output. Based on a plausible explanation for these phenomena, simple experiments have been performed in the laboratory to reproduce the observations. This is the first of a series of reports on the subject.

I. Introduction

Many sources contribute to the generation of spurious signals—noise bursts and intermodulation products (IMPs)—on an antenna. On a diplexed antenna, a complex arrangement of filters permits simultaneous transmission (e.g., at 2115 MHz) and reception (e.g., at 2295 MHz) of signals. All nonlinear components in the transmission link from power-klystron to the feed horn are potential sources of interference. However, even after painstaking elimination of all these internal sources of noise, there appears to remain an external source of noise which limits the ultimate sensitivity of diplexed antenna systems.

A proposed explanation for an external source of interference is given in this report with experimental

evidence to support the theory. In the proposed model, the large reflector antenna is seen as a structure composed of many small sections of aluminum panels bolted or riveted to the main structure. Thus the reflecting surface contains an extremely large number of Al-Al₂O₃-Al junctions because of the natural tendency for aluminum surfaces to form oxide layers. Furthermore, the thickness of the Al₂O₃ on all aluminum surfaces is of the order of 30-70 Å, which just happens to be in the correct range to allow electrons to tunnel through with ease (Ref. 1). However, a characteristic of tunneling electrons, according to quantum mechanics, is that the current-dependence on voltage is very nonlinear. Hence an antenna is replete with microscopic diodes as conjectured by many who had observed the noise bursts and IMPs.

This report describes the results from a few simple laboratory experiments which provide convincing proof of the plausibility of the above model of an antenna.

II. Microwave Experiments

In a later report the detailed theory of noise bursts and IMP generation will be given. Here we summarize the characteristics of the metal-insulator-metal (MIM) junction, in particular Al-Al₂O₃-Al, and describe some results of microwave experiments using these MIM junctions.

In contrast to classical physics, quantum mechanics predicts that electrons can traverse a MIM junction provided the insulator is not too thick relative to the deBroglie wavelength of electrons. Moreover, the tunneling current increases exponentially with voltage applied across the junction. To be sure, many other mechanisms contribute to leakage currents across the junction. However, these are ohmic (linear with voltage) and contribute little of interest.

Two important points should be noted before discussing the experiments: (1) tunneling currents can be appreciable—several milliamperes per volt, and (2) the inherent oxide layer on commercial aluminum is a few tens of Å thick and just right for tunneling to occur.

In order to duplicate the results observed on the antennas at Goldstone, a simple experiment was performed in the laboratory as shown in Fig. 1. An Al-Al₂O₃-Al junction was exposed to microwave power from signal generators at frequencies f_1 and f_2 , and spurious signals generated at f_3 were analyzed via sensitive instrumentation as shown. Considerable caution was taken to ensure that what was observed was indeed generated at the MIM junction. Variations in the mechanical forces at the junction produced changes in the output signal which left little doubt as to the origin of the spurious signals. As further proof of the validity of the model, it was demonstrated that a threshold of around $\frac{1}{2}$ W of power was required to produce the expected noise bursts and intermodulation products. Based on the waveguide used, this threshold amounts to a power density of 85 W per square meter and extrapolates to a threshold of around 40 kW transmitted power on a 26-m antenna. This is in good agreement with the observed threshold of around 10 kW.

The following tabulation shows typical values of the various parameters in the experiment:

$$f_1 = 2111 \text{ MHz } (\frac{1}{2} \text{ W})$$

$$f_2 = 2115 \text{ MHz } (\frac{1}{2} \text{ W})$$

$$f_3 = f_2 + N (f_2 - f_1)$$

$$N = 40 \text{ to } 50 \text{ (see Fig. 2)}$$

The axial width of the junction, separating the left section from the right, was around 1 mm.

Figure 2 shows typical output spectra from the receiver. The lower trace shows the thermal noise from the resonant cavity when no signals were incident on the MIM junction. The upper trace shows the increased noise level and intermodulation products when the two signal generators were turned on. Furthermore, it was possible to vary the spectra by changing the mechanical forces on the MIM junction or by varying the power from the signal generators. These results are in general agreement with the observations on an antenna.

On an antenna the reflecting panels are riveted to supporting members of the main structure. Thus near each rivet (and including the rivets themselves) two pieces of aluminum are in juxtaposition to each other with an aluminum oxide layer between the two surfaces. These junctions are exposed to the direct radiation from the transmitter, and they are in position to reradiate spurious signals back to the receiving system. On a 64-m antenna there are nearly 2×10^5 rivets; thus if at any instant only 1% of the riveted junctions had the correct conditions for electron tunneling, there would be some 2000 such junctions. Moreover, as the antenna moves, these junctions would show a dynamic change in characteristics from instant to instant and from one location to another.

If indeed the noise-bursts and generation of IMPs are due to the nonlinear characteristics of electron-tunneling in MIM junctions as described here, an easy way to eliminate the problem is to anodize all surfaces, including rivets, so that all metal (aluminum) surfaces will be covered with 100 to 200 Å of Al₂O₃. Unfortunately, this must be done before an antenna is assembled. Future articles will describe the exact mechanism responsible for these phenomena.

Reference

1. Duke, C. B., "Tunneling in Solids," in *Solid State Physics, Vol. 10*, Academic Press, New York, 1969.

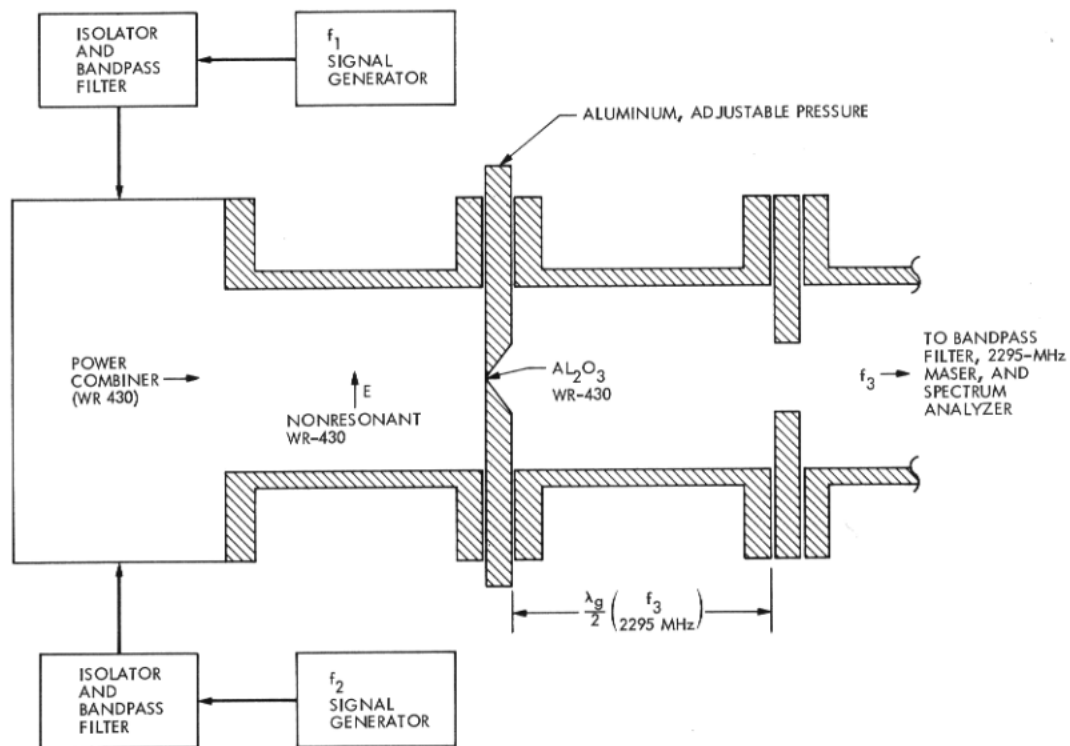


Fig. 1. Schematic diagram for generating noise bursts and intermodulation products

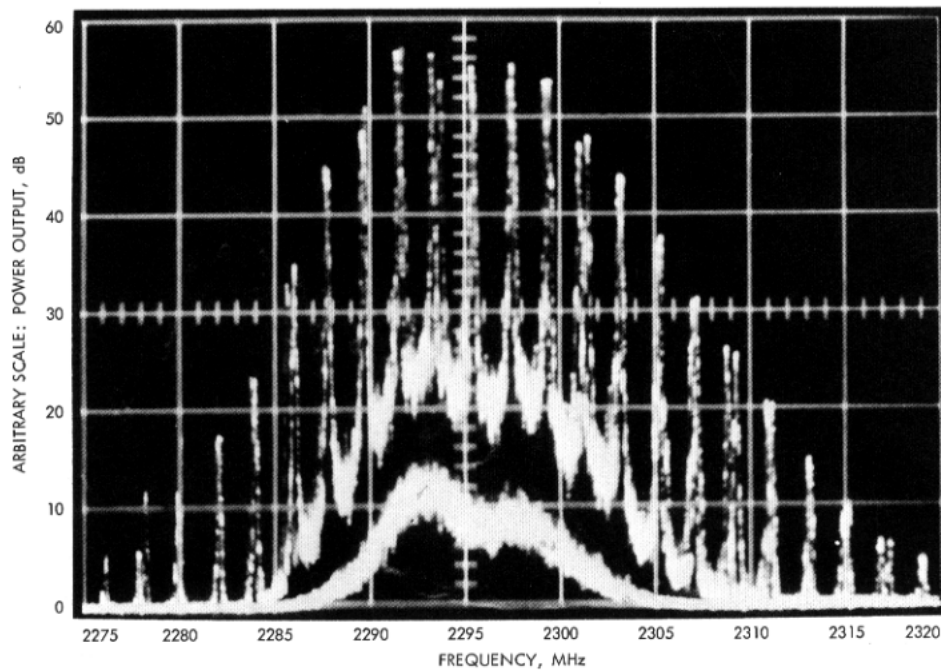


Fig. 2. Typical spectra from experiment. Lower trace shows thermal noise from resonant cavity. Upper trace shows IMP superimposed on noise burst